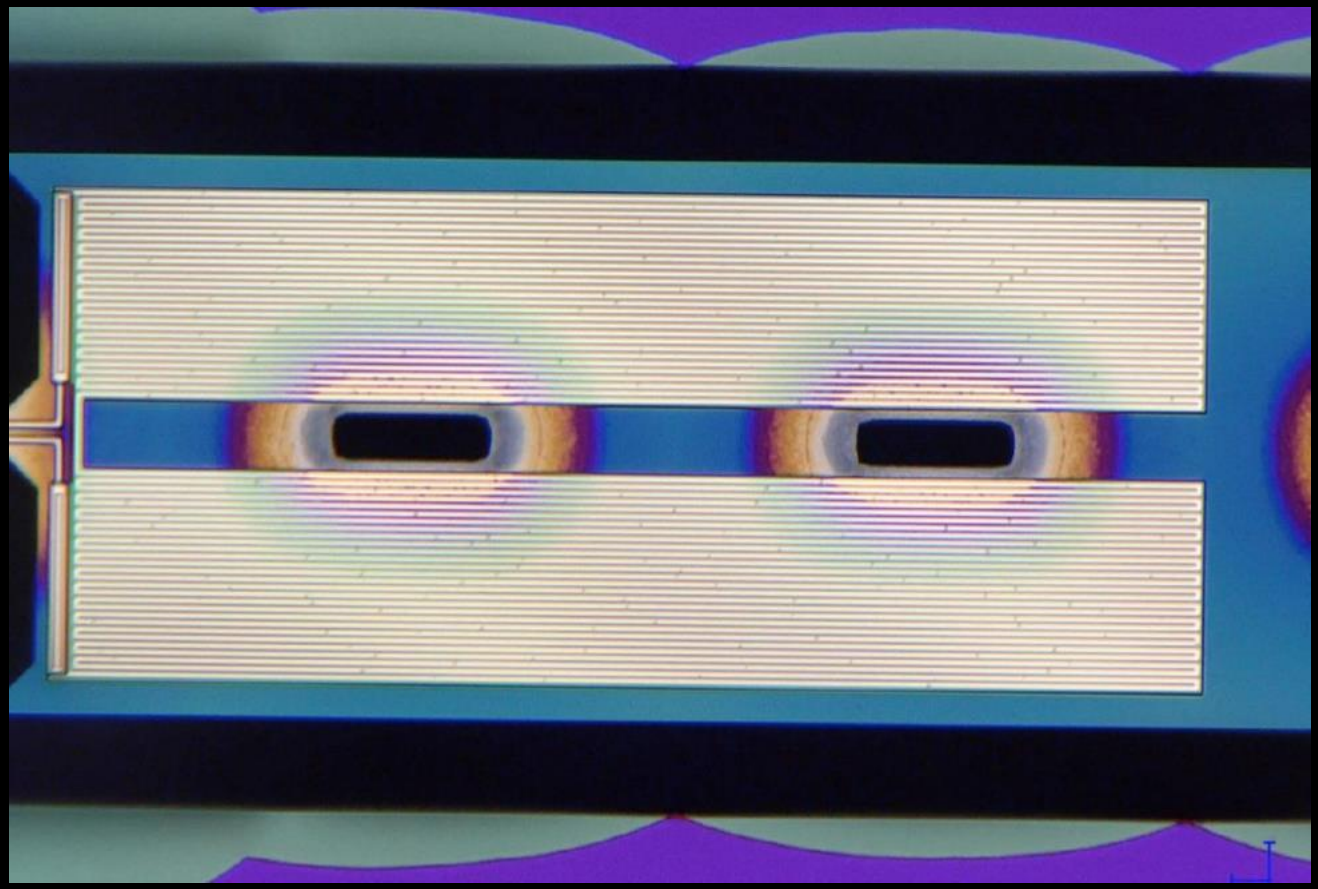
TKIDs for CMB Polarimetry & Submillimeter Astrophysics



Roger O'Brient
Jet Propulsion Laboratory, California Institute of Technology
August 17, 2017

Team Members

JPL:
Roger O'Brient
Hien Ngyuen
Anthony Turner

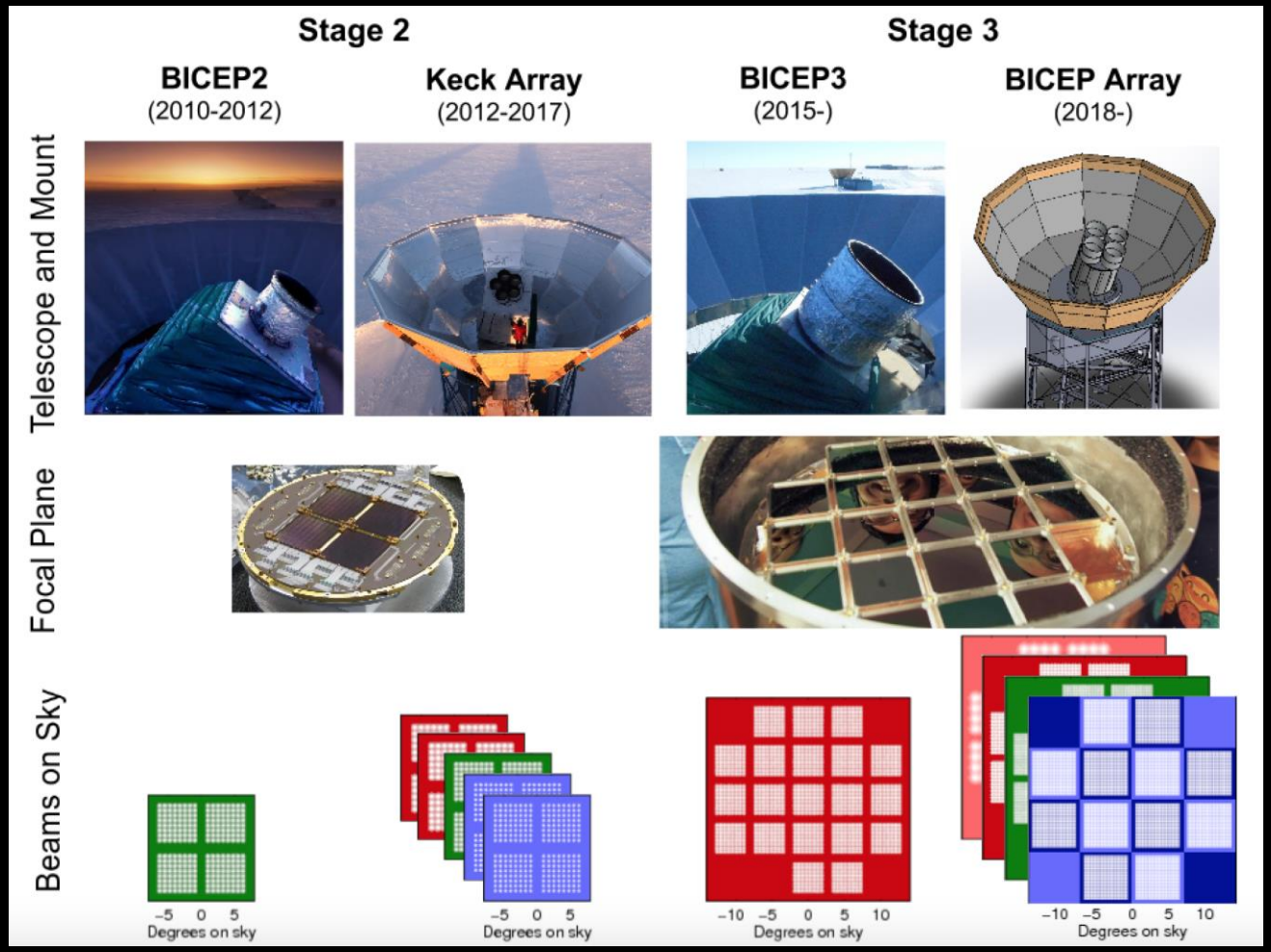
Caltech:
Bryan Steinbach
Jamie Bock
Jonas Zmuidzinas

Interested postdocs please talk with me

Outline

- Motivation
- Sensitivity Model
- Prototype
- Lab characterization
- Next Steps

Motivation



- Howard Hui will talk about BICEP3 Thursday
- It's a "high five" talk about how it works well

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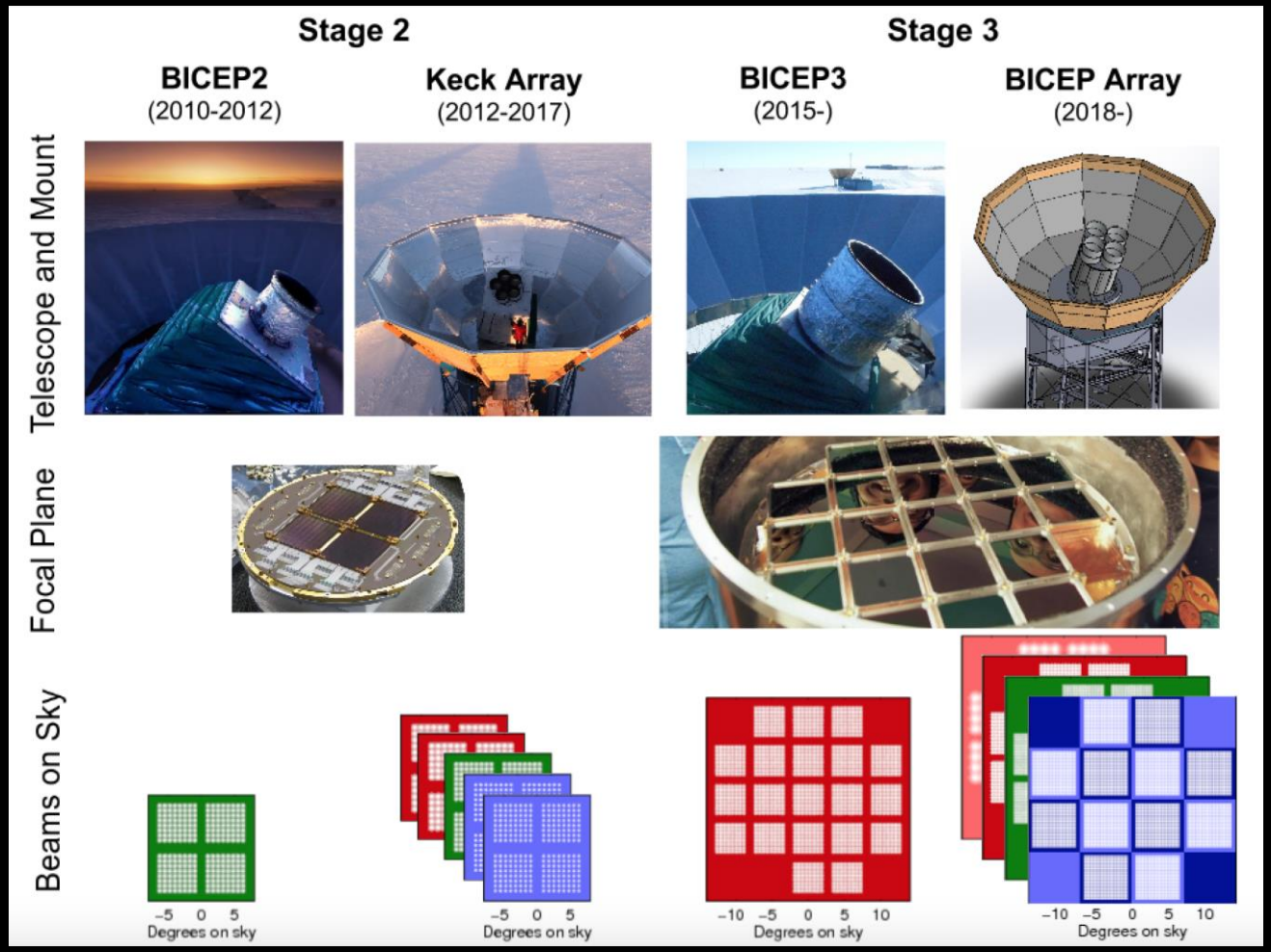
Motivation



- BICEP Array 150GHz: ~7,000 detectors
- BICEP Array 250GHz: 20,000 detectors

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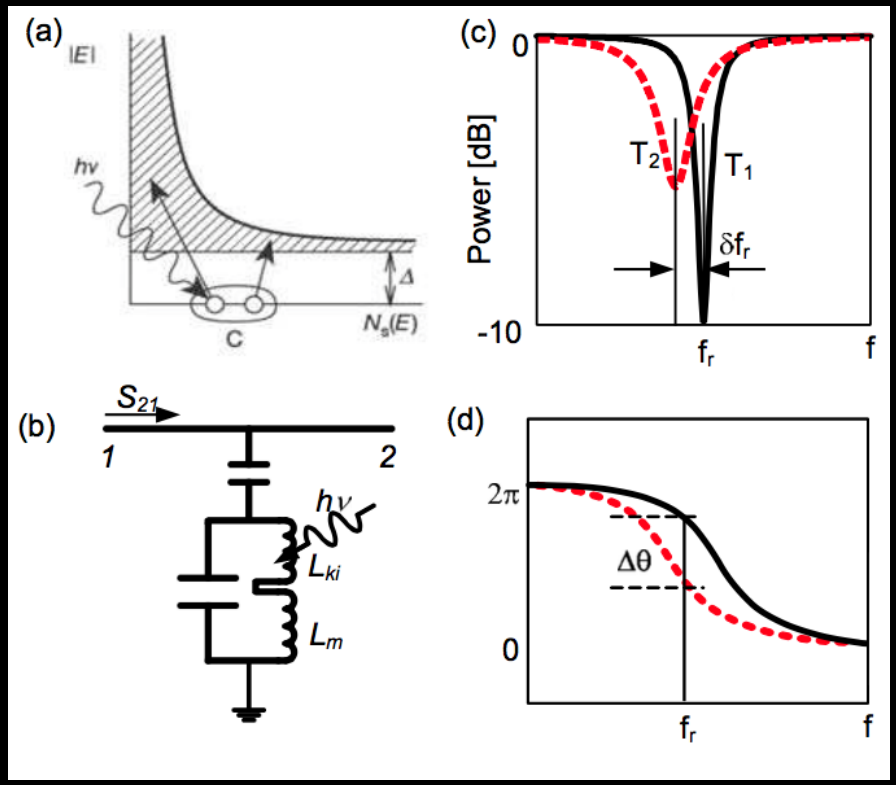
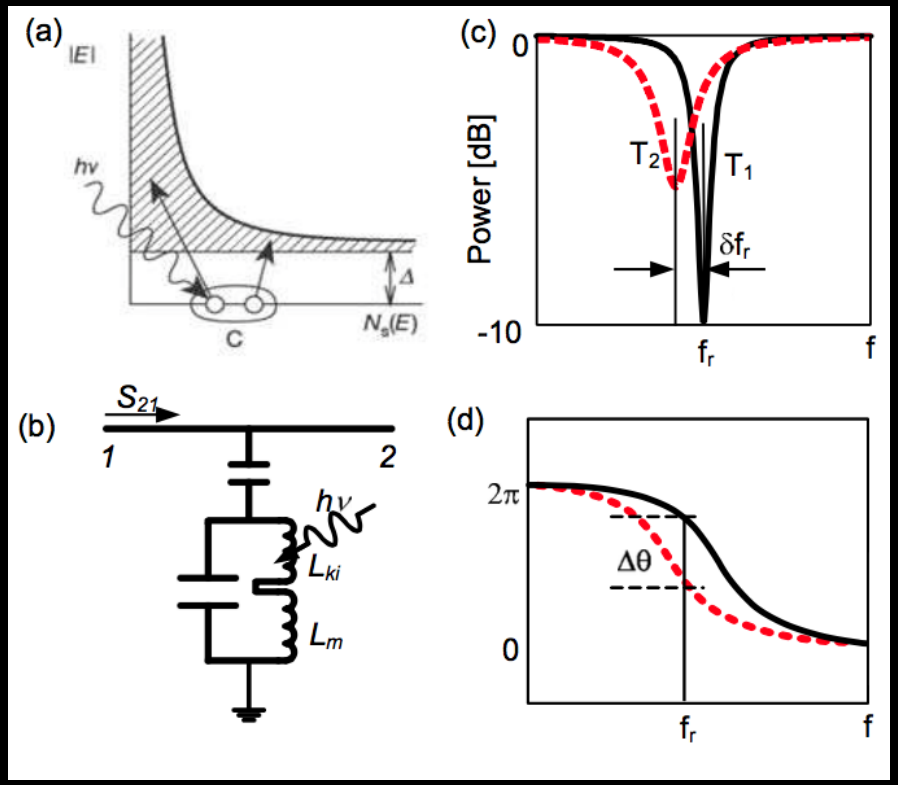
Motivation



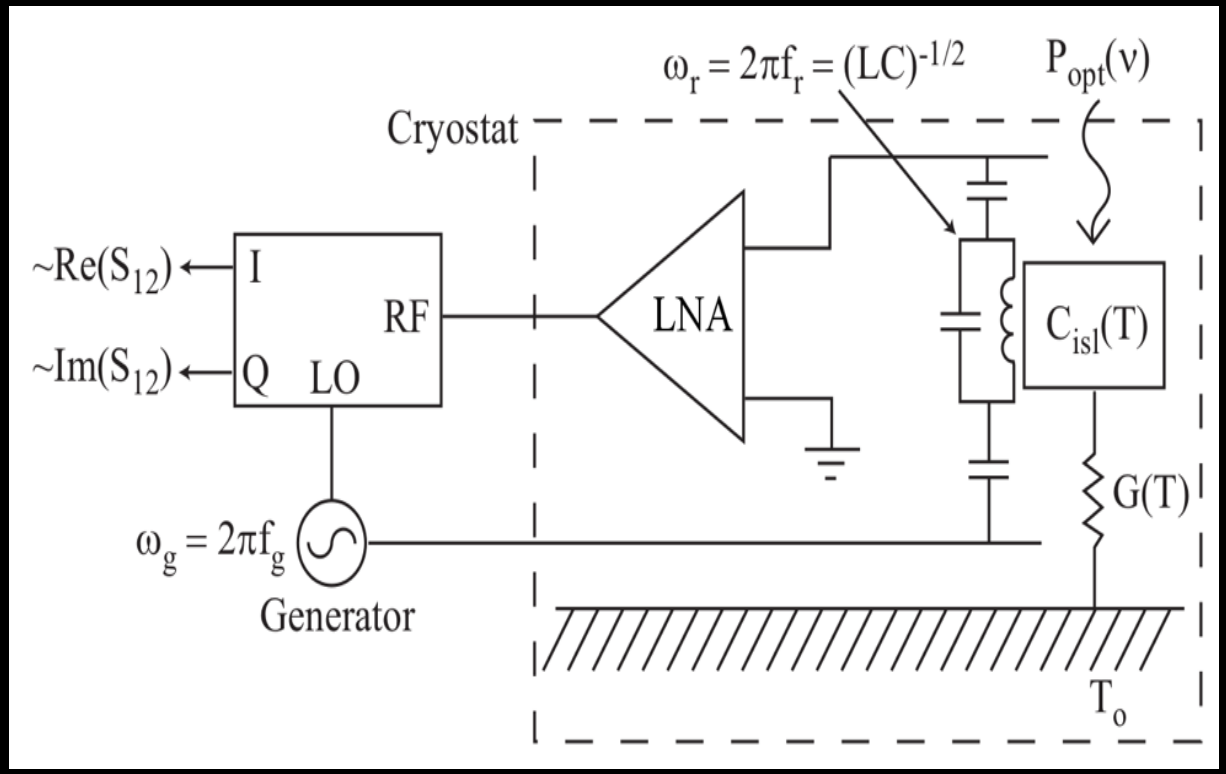
- KIDs are maturing rapidly
- RF-FMUX
- High MUX factor
- Not bolometers: a-thermal devices

Motivation



- KIDs are maturing rapidly
- RF-FMUX
- High MUX factor
- Not bolometers: a-thermal devices
- Resonator needs to:
  1. Absorb photons with high efficiency
  2. Provide high responsivity

Thermal KIDs (TKIDs)



- This *is* a bolometer- thermalizes power
- Inductor replaces TES or NTD-Ge
- Island Temperature changes with loading
- Resonator S_{21} detects *phonons*
- Absorber and sensor are distinct
- Drop in compatible with antenna-coupled designs

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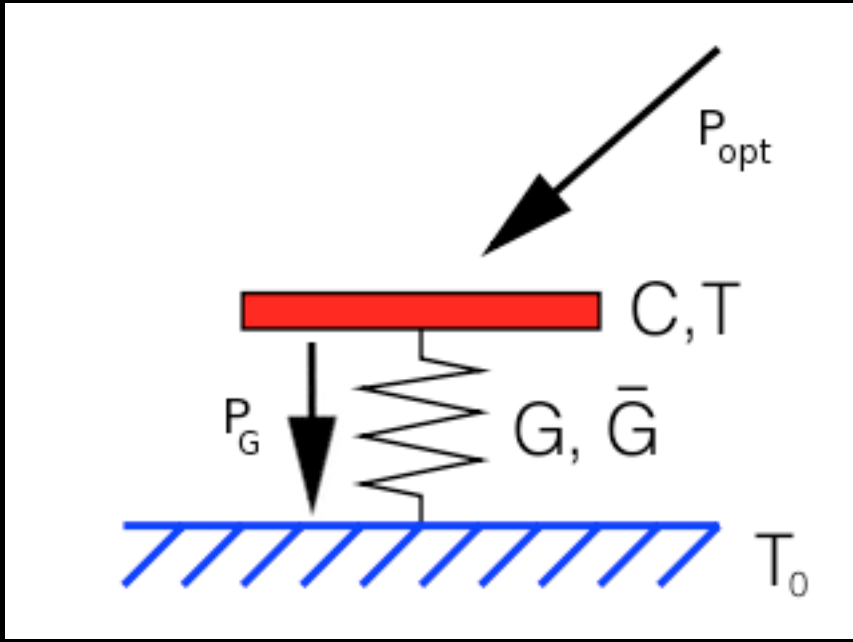
Bolometer Theory



$$\partial T(\nu) = \frac{\partial P(\nu)}{G} \frac{1}{1 + j2\pi\nu\tau}$$

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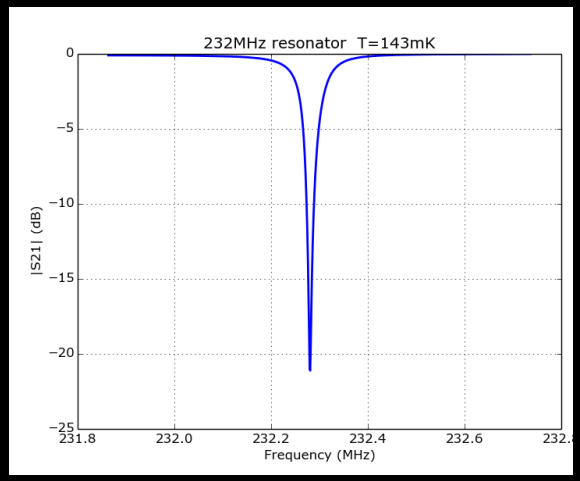
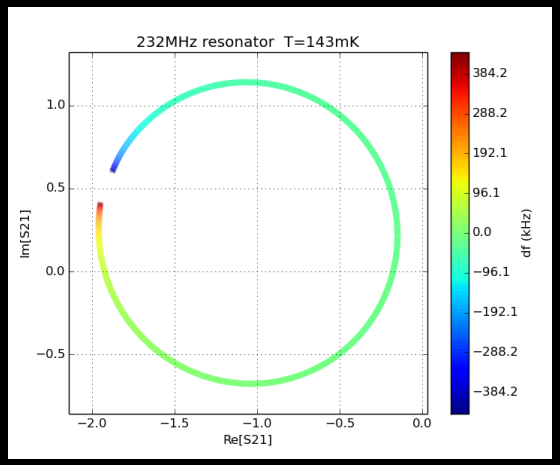
KID Theory

$$n_{th}(T) = 2N_o\sqrt{2\pi k_B T\Delta}e^{-\Delta/k_B T}$$

$$\partial S_{21} = \frac{\chi_c\chi_{qp}}{4}\left[1 + j\beta(\omega_g, T)\right]\frac{\partial N_{qp}}{N_{qp}}$$





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TKID Responsivity

$$S \equiv \frac{\partial S_{21}}{\partial P} = \frac{\chi_c \chi_{qp}}{4} \left[1 + j\beta(\omega_g, T)\right] \left[\kappa \frac{\tau_{qp}}{\tau_{th}} \frac{1}{GT}\right]$$

$$NEP_*^2 = \frac{|\partial S_{21,*}|^2}{S^2}$$

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BICEP Array Noise Budget

Frequency [GHz]	90	90	150	150	250	250
Component	δQ_i^{-1}	$\delta\omega_r/\omega_r$	δQ_i^{-1}	$\delta\omega_r/\omega_r$	δQ_i^{-1}	$\delta\omega_r/\omega_r$
Photon Shot [aW/√Hz]	16.6	16.6	35.7	35.7	77.2	77.2
Photon Bose	21.7	21.7	46.7	46.7	79.8	79.8
Leg Phonons	17.7	17.7	29.7	29.7	49.7	49.7
Gen-Recombination	0.869	0.869	0.245	0.245	0.685	0.685
Amplifier	51.1	10.2	85.9	17.2	144	28.7
TLS	0	8.28	0	23.4	0	65.3
Photon Totoal	27.3	27.3	58.8	58.8	111	111
Non-photon Total	54.0	21.7	90.9	41.5	152.3	86.9
Total	60.6	34.1	198	68.1	188	188

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Anticipated Sensitivity in Various Environments

Platform	Wavelength [μm]	Optical Loading [pW]	NEP_{photon} [aW/√Hz]	NEP_{det} [aW/√Hz]
Atacama (CSO/LCT)	350	43	240	86.7
Atacama (CSST)	850	19	110	56.9
Balloon (SPIDER 250GHz)	1200	2.7	31	21.5
Balloon (BLAST-pol)	250	23	200	63.1
Balloon Spectrometer	250	0.18	18	5.65
Hershel-SPIRE	250	4.5	85	27.8
Planck-HFI	2100	0.3	8	7.3
BLISS/SAFARI*	100	10^{-6}	0.06	0.07

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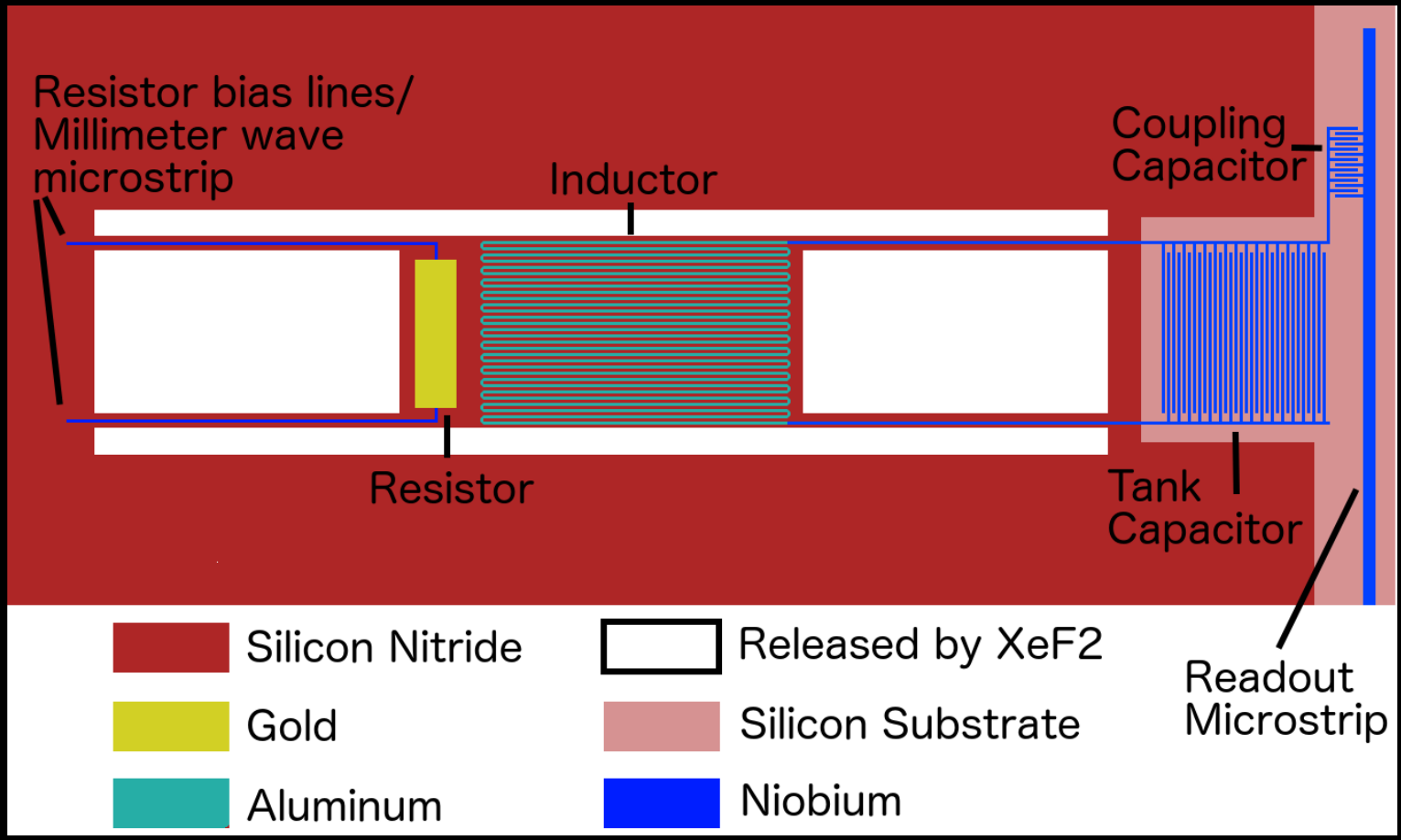
Prototype Detectors



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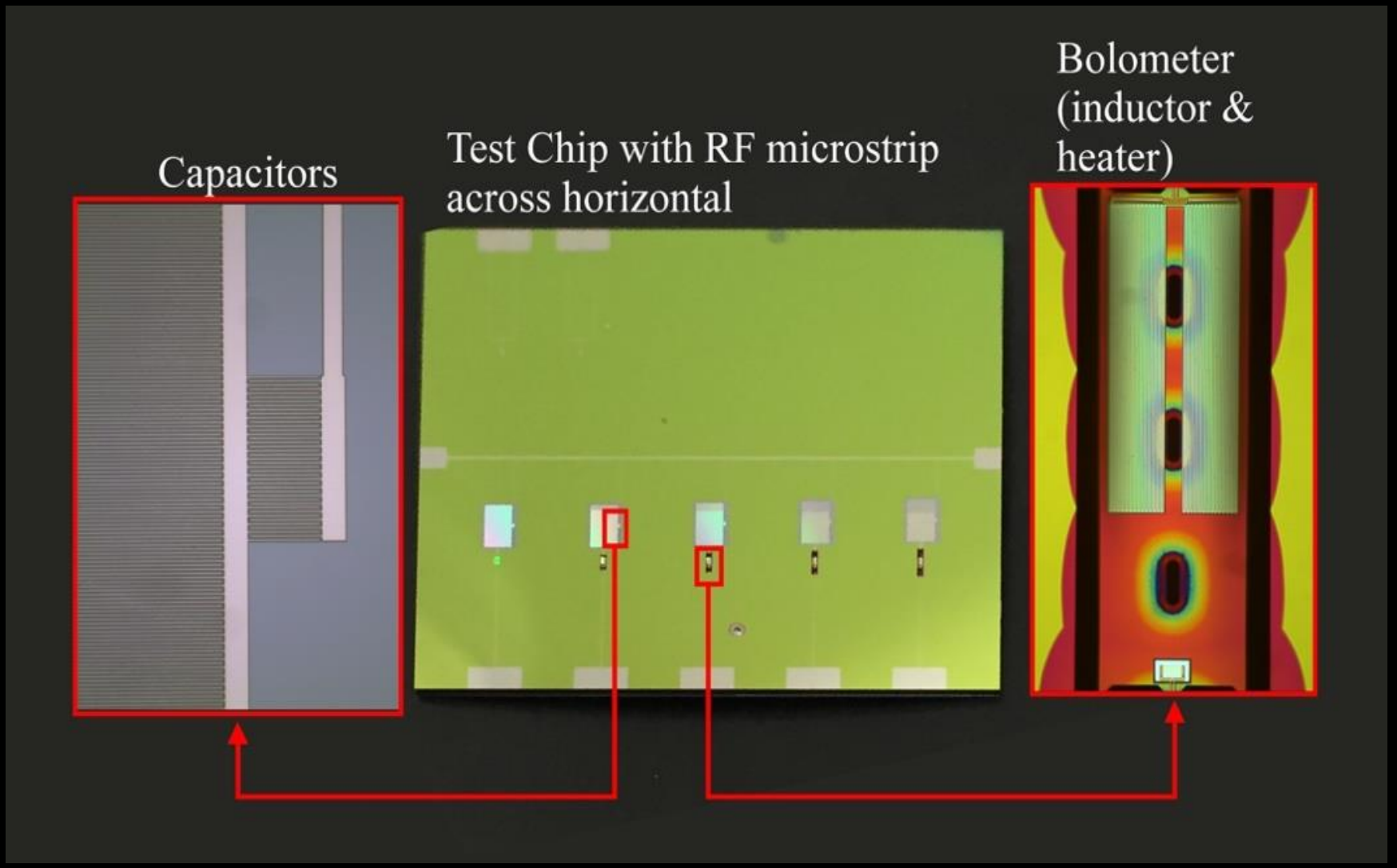
Prototype Detectors



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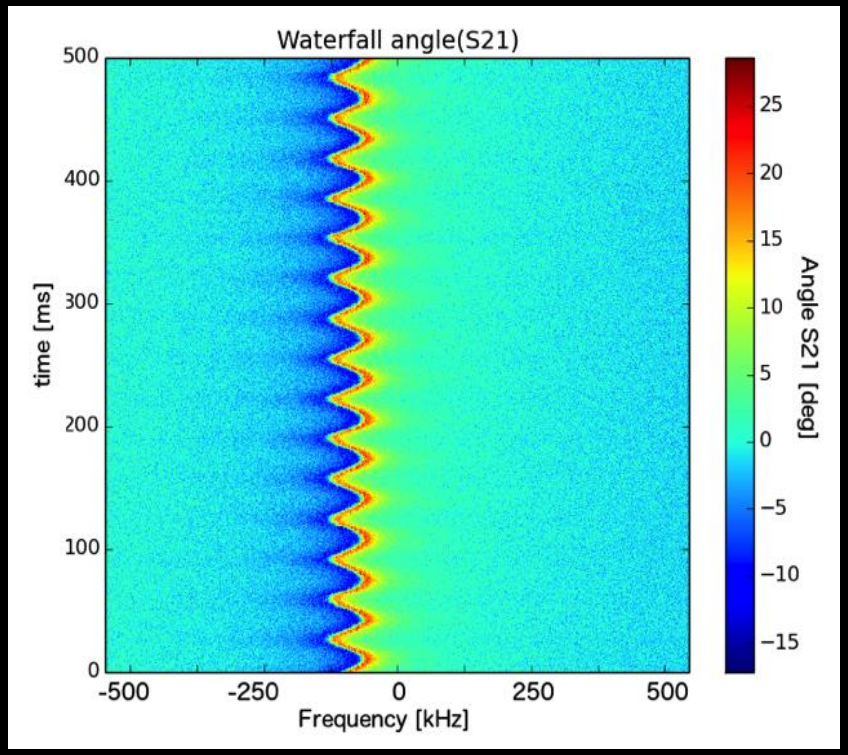
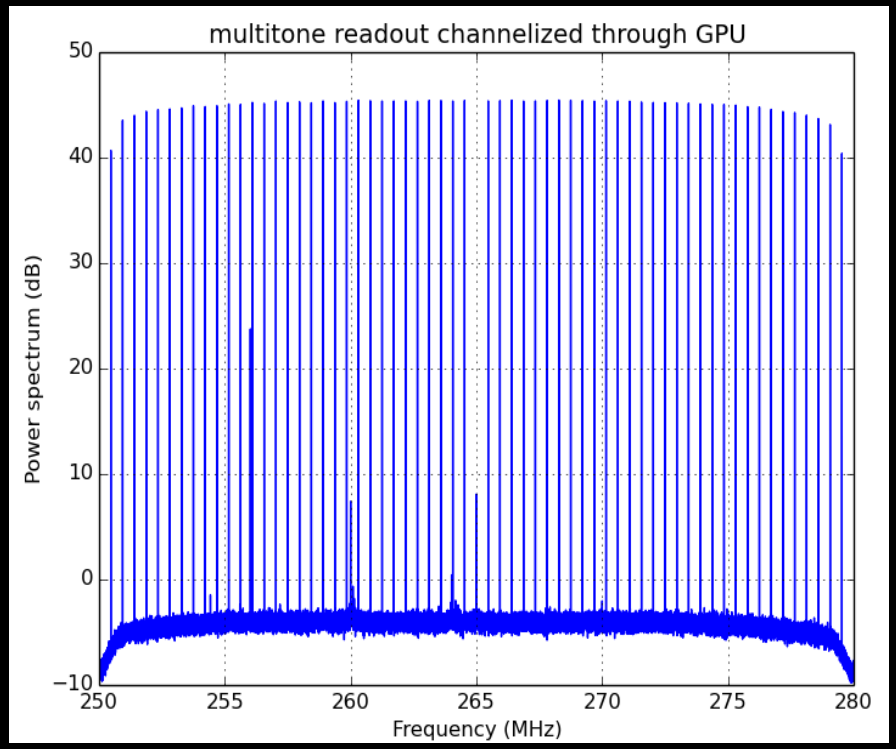
GPU accelerated Chirped readout





- National Instruments Universal Software Radio Peripheral (USRP)
- Can FFT in either CPU or GPU.
- Coordinated through C++
- Reconfigurable: single tone, white noise, spin echo, etc.

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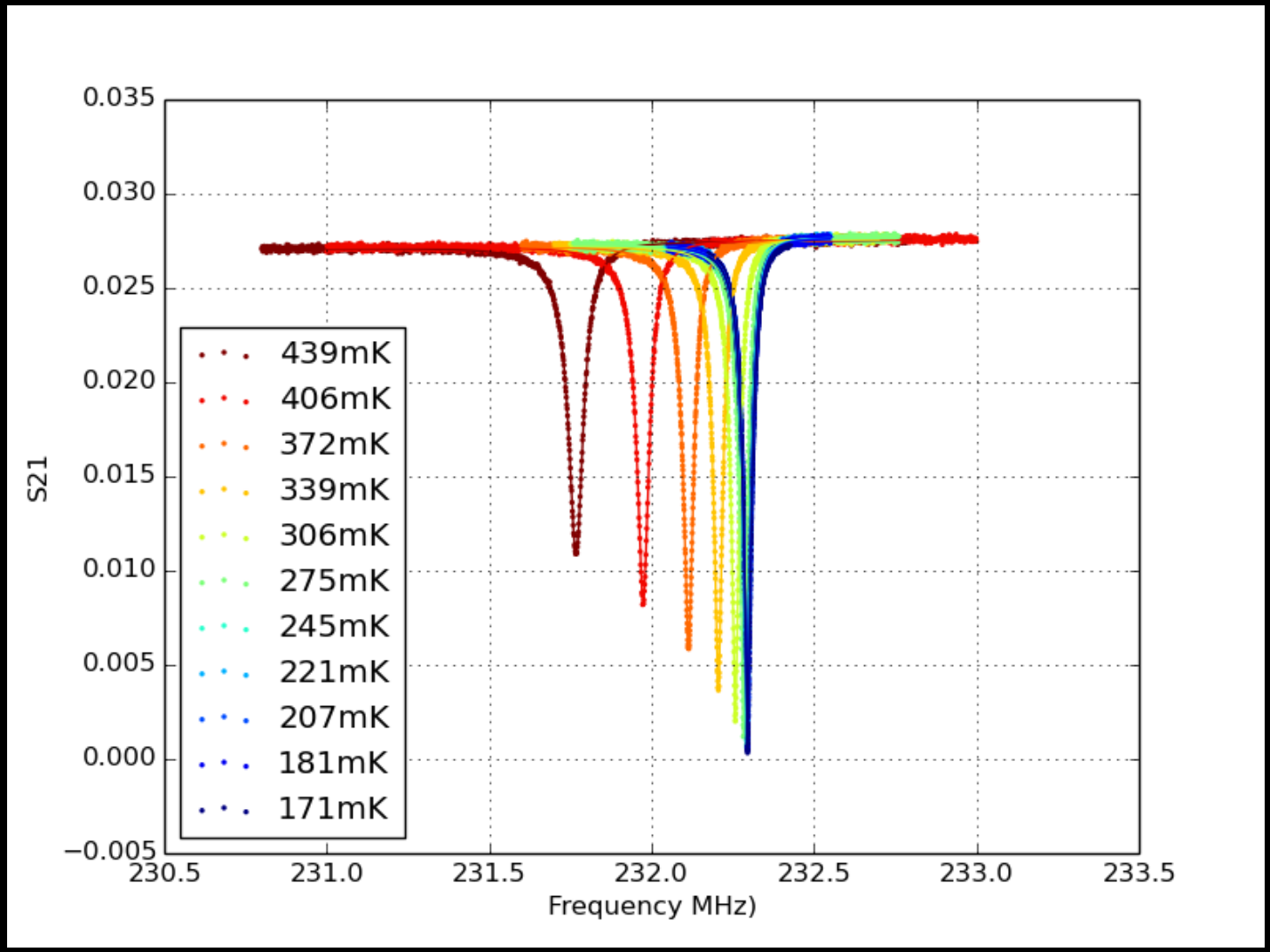
Unreleased pure Al resonator



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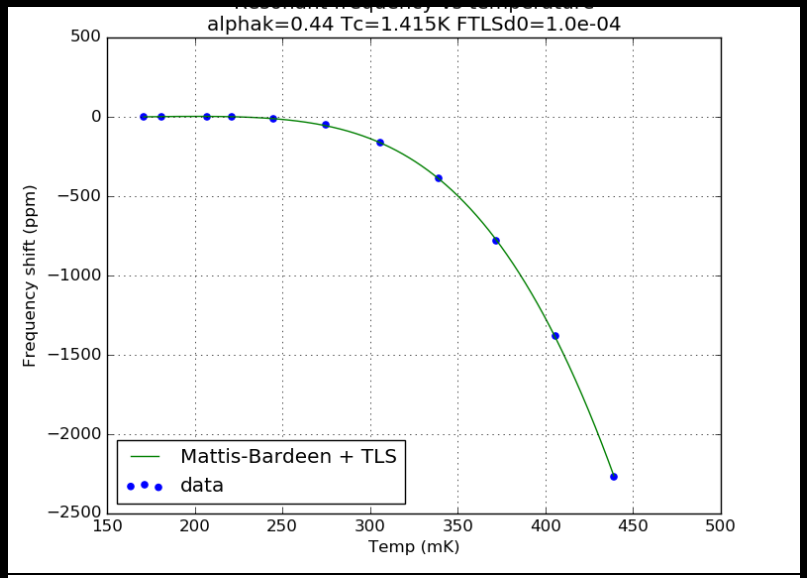
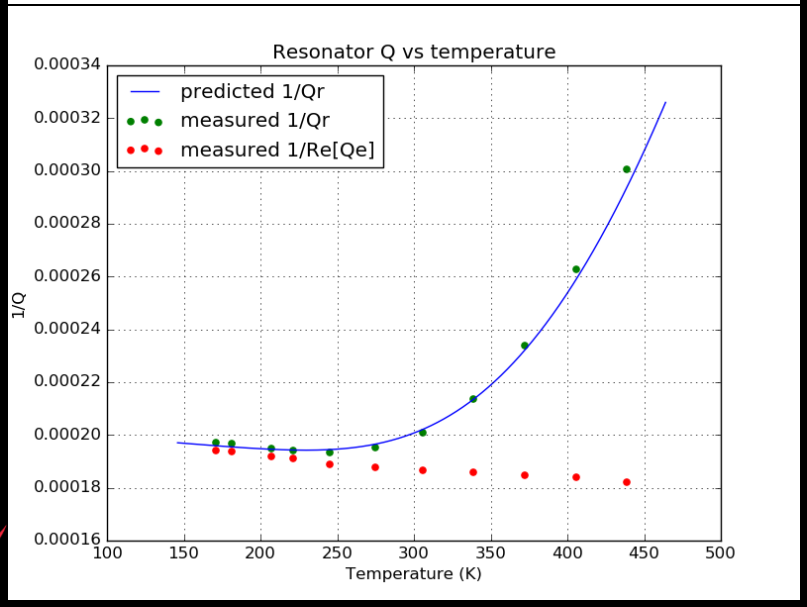
Unreleased pure Al resonator





- Well modeled with Mattis-Bardeen Theory

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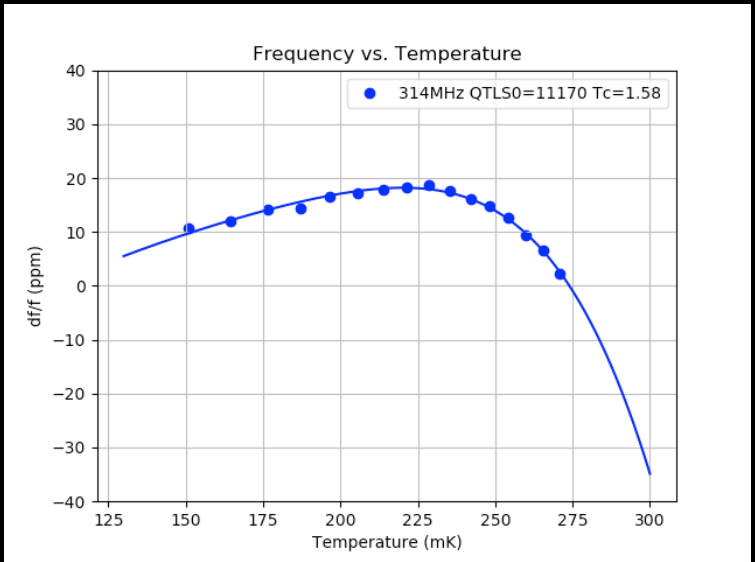
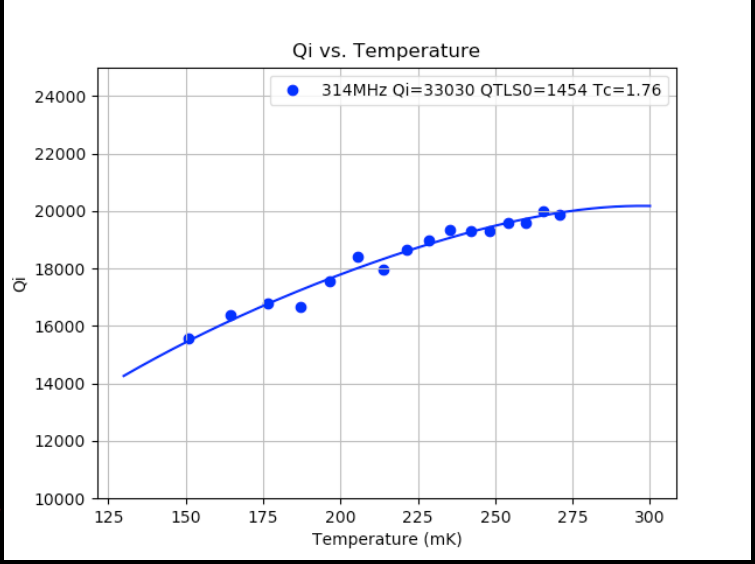
Released TKID (v 1.0)



- TLS can shift the resonator frequency



- $\delta_{\mathrm{TLS}} = \delta_o \tanh(\hbar\omega/2kT)$

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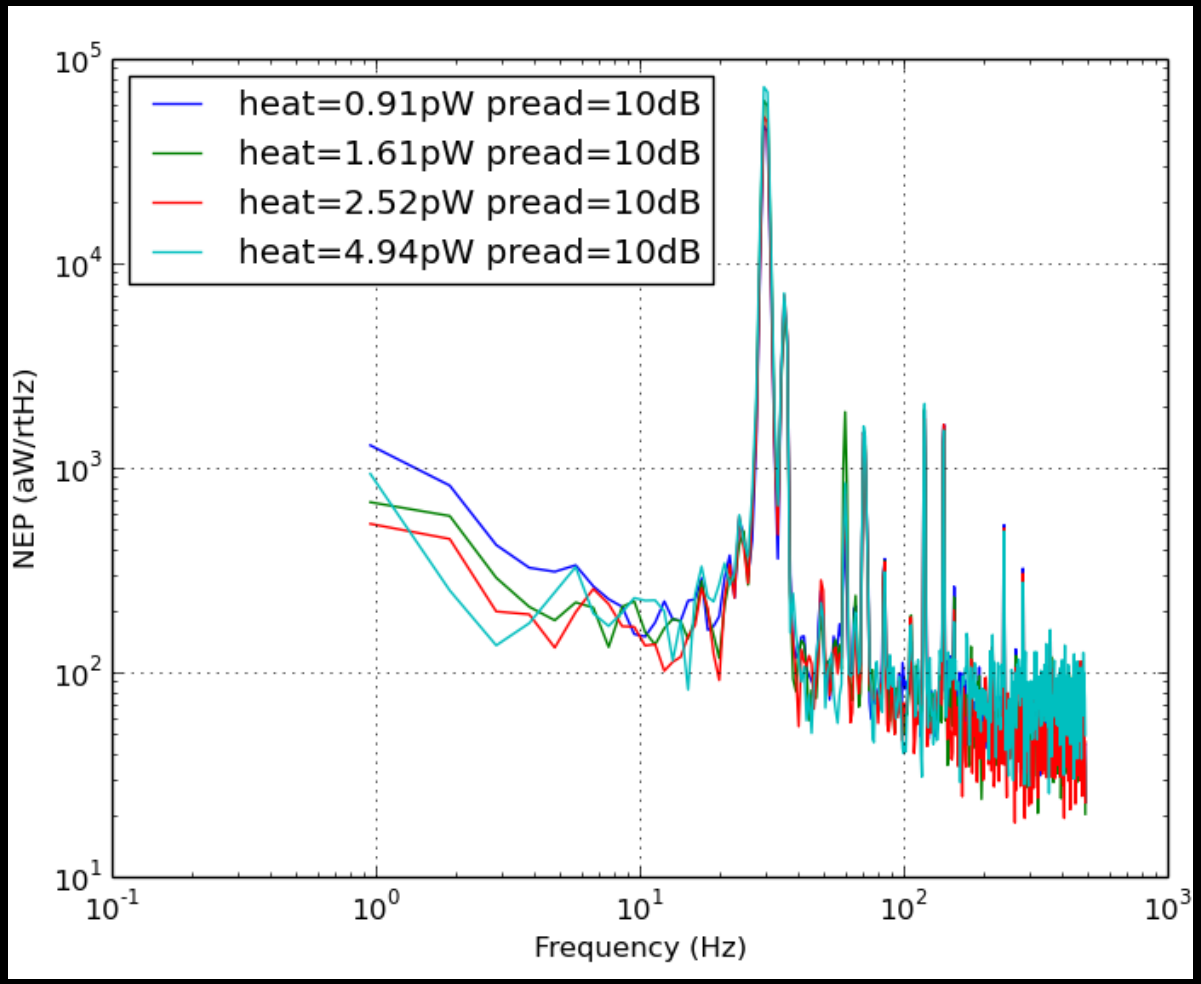

- Ignore deliberate 30Hz peak
- Microphonics at low freq
- White noise floor 100-150 aW/rtHz
- Requirement: 87 aW/rtHz

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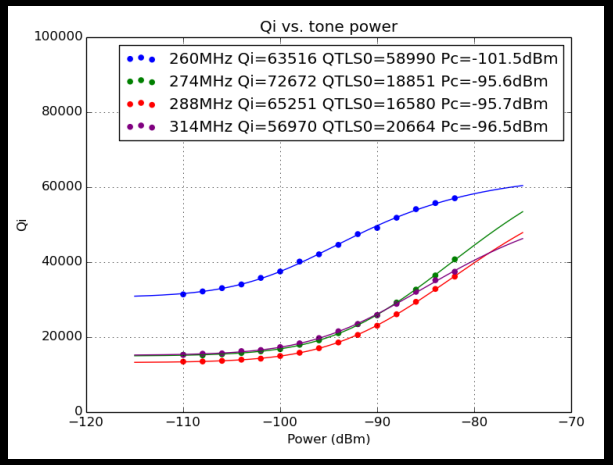
Q Measurements of TKID

$$\frac{1}{Q_i} = \frac{1}{Q_{TLS}} + \frac{1}{Q_o}$$

$$Q_{TLS} = Q_{TLS,o}\sqrt{1 + P/P_c}$$

Q vs Read power



- Suggestive of TLS despite capacitor off LSN

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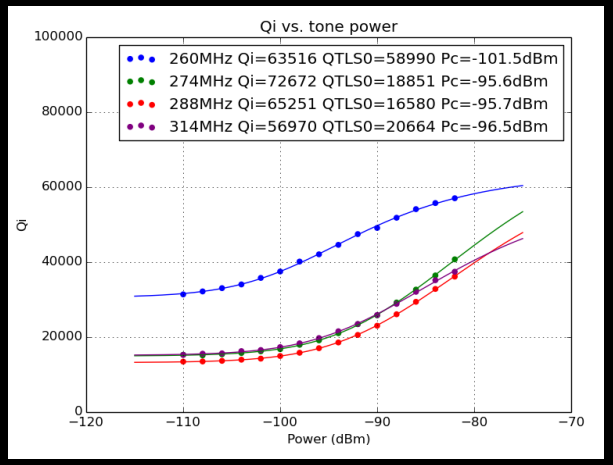
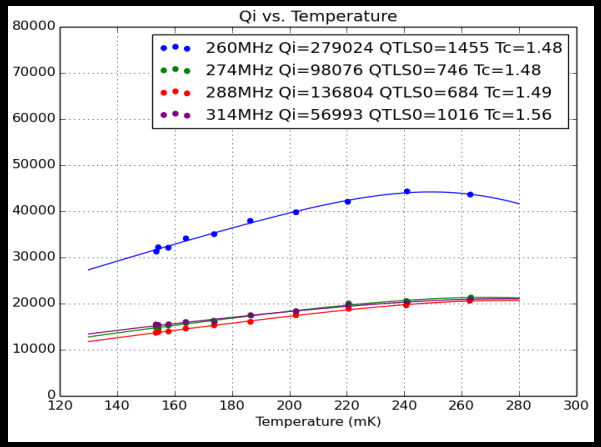
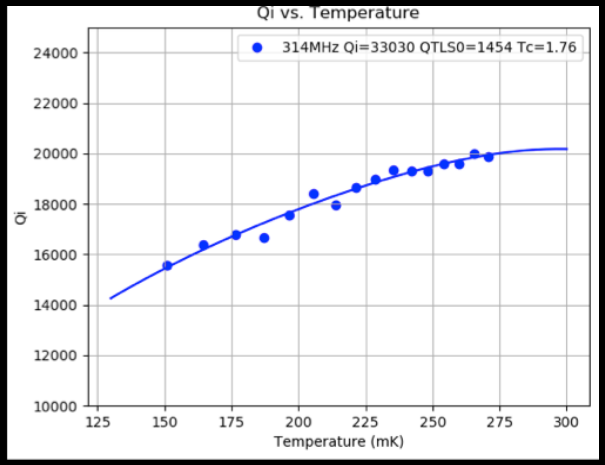


- Suggestive of TLS despite capacitor off LSN
- Contributions both on & off island
- Simulations suggest negligible capacitance in inductor
- No evidence of junction between Al & Nb

Q vs Island temp



Q vs bath temp



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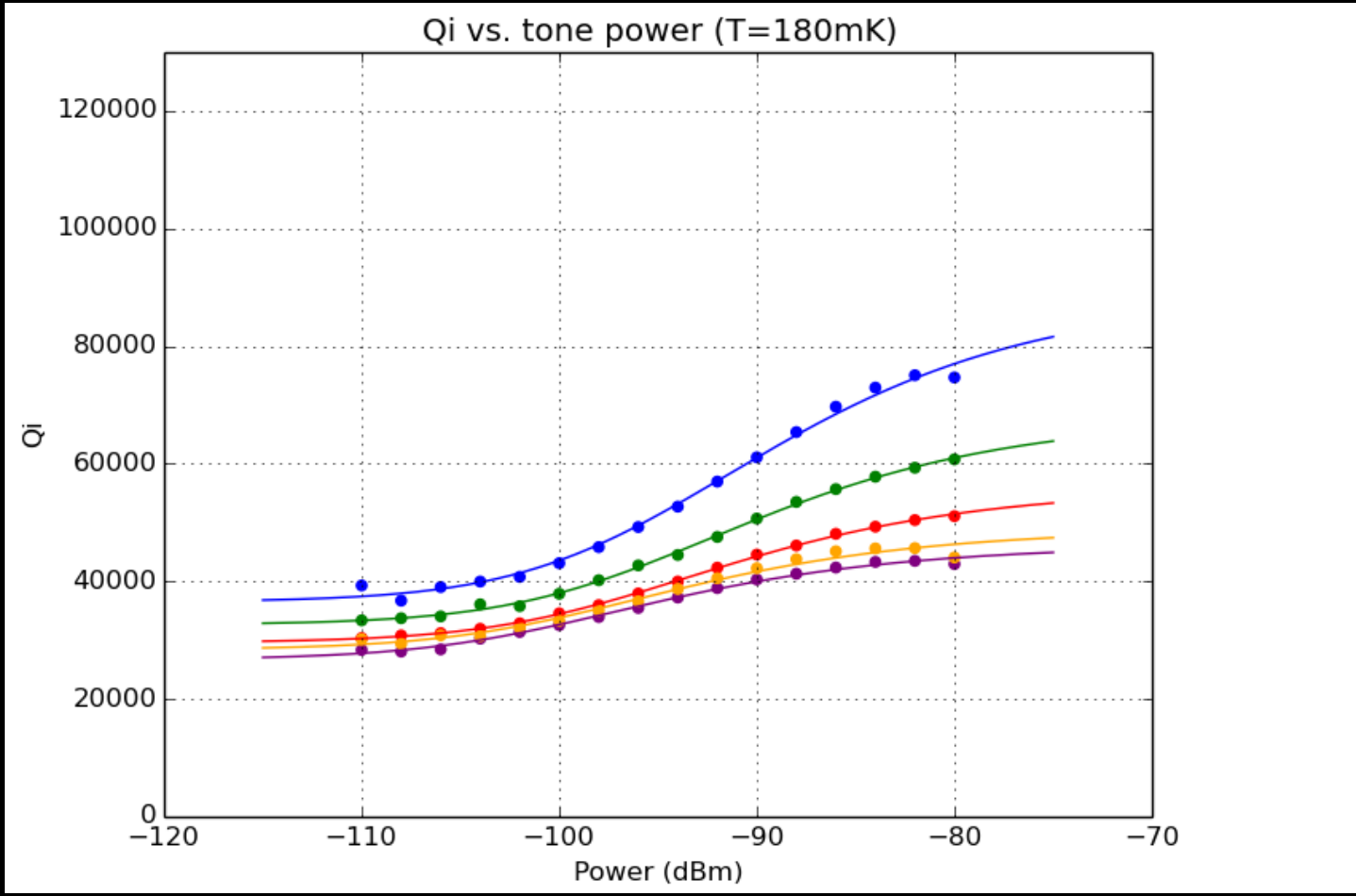
unreleased TKID, no Nitride



- Low Qs even without Silicon Nitride.

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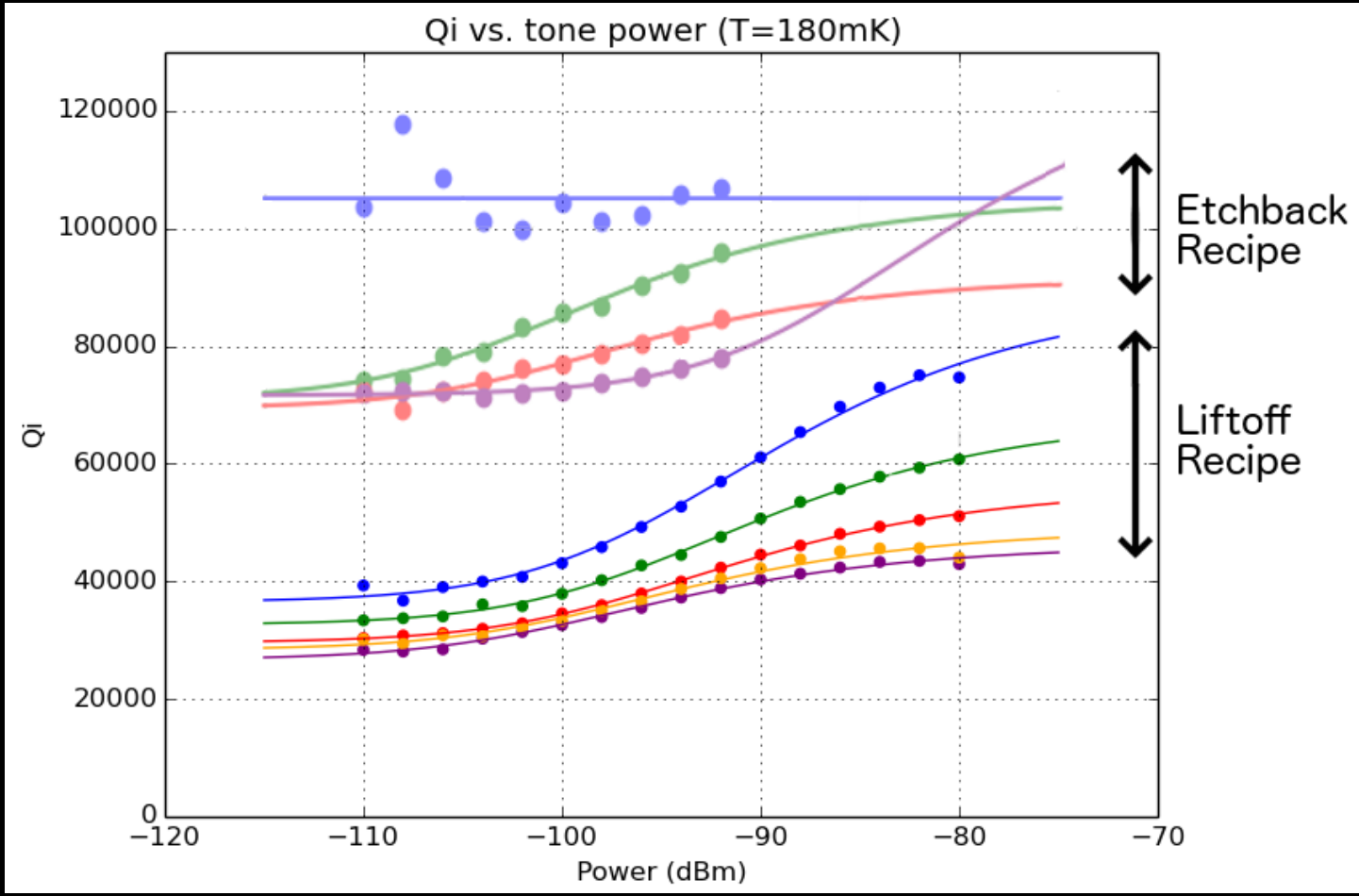
unreleased TKID, no Nitride



- Lift-off processing appears to skunk the Nb
- Qs higher with etched processing

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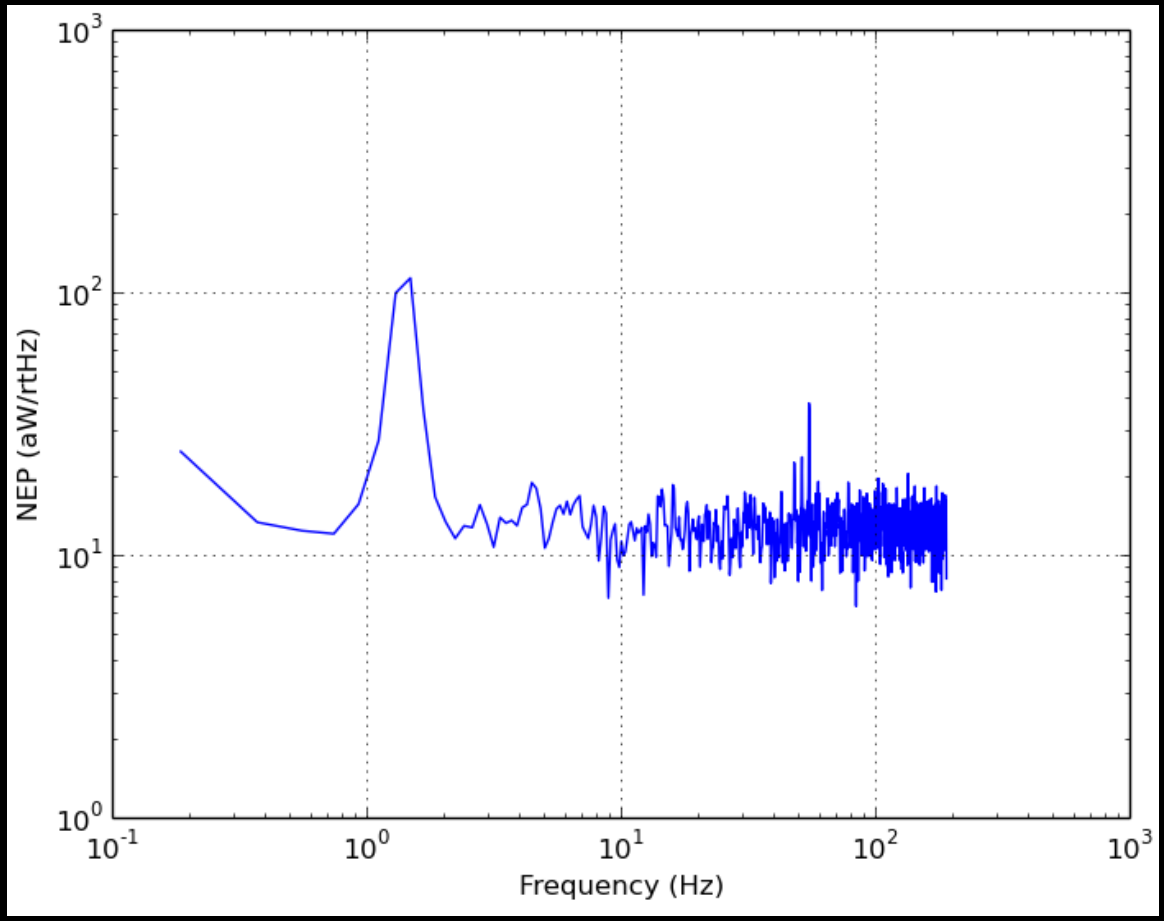
unreleased TKID, no Nitride



- TLS noise under control here
- *Almost* finished fabricating new bolometers with etched Nb…

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What's next

- Testing fixed bolometer
  - If still have TLS effects, consider using Si legs (like GSFC detectors)
- Fix microphonics peak with a proper stage
- Antenna coupled devices in FY18
- Deployable array modules in FY19

Thank you

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